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RaSTA 2.0 – DEVELOPMENT OF A COMPACT SAMPLE TEST CAVITY FOR SURFACE RESISTANCE MEASUREMENTS

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Abstract

RaSTA, the Rapid Superconductor Test Apparatus, is a sample test cavity project at HZB. It shares the sample geometry and the calorimetric measurement principle with the QPR but is targeted at quicker turnaround times and a more compact footprint at higher operating frequency. RaSTA 2.0 features a niobium coated copper cavity allowing for higher RF field levels and better thermal stability. The outer dimensions have been reduced to fit the system inside a compact cryostat; sample handling and tooling have been revised for reduced overall complexity. RaSTA can be operated without radiation shielding and the entire system is intended to be transferable to labs without extensive SRF infrastructure. We present the design and construction of RaSTA 2.0 together with operating considerations and first data obtained with the new cavity.

INTRODUCTION AND BACKGROUND

The Quadrupole Resonator (QPR) is a well-established tool for surface resistance (R_S) measurements of superconducting materials, particularly in the context of SRF thin films [1]. However, QPR experiments are time-consuming and require a cryogenic and RF infrastructure very similar to vertical tests of single-cell cavities. For SRF material R&D, especially the optimization of thin-film coatings, the number of samples to be tested quickly exceeds the available test slots. Hence, a tool for pre-selection of samples is desired, that ideally even provides enough accuracy for certain applications.

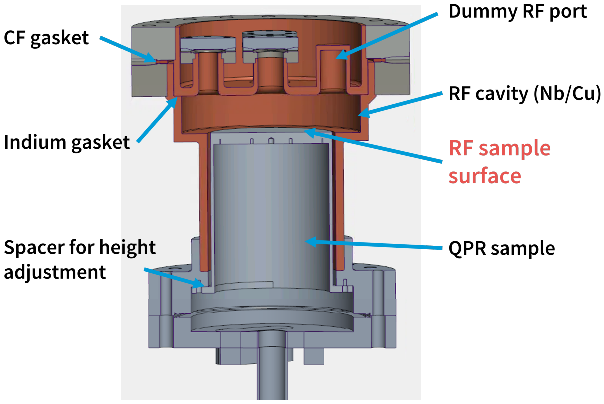

Figure 1: Schematic of the RaSTA 2.0 cavity design. Highlights of the new design are: Dummy RF ports for field symmetry, the separated sealing concept with indium wire and CF gasket, spacers for sample height adjustment.

To meet this need, the Rapid Superconductor Test Apparatus (RaSTA) was developed [2]. The guiding principle of RaSTA is to retain the QPR sample geometry and the successful calorimetric measurement concept with direct access to R_S vs. T data while making the setup very compact. Most of the complexity and time requirement of QPR tests is closely related to the experimental infrastructure, such as the cryogenic plant operating the LHe bath cryostat and radiation safety measures that are needed for measurements at high RF field levels. In order to fit RaSTA into a small and manually operated LHe cryostat without radiation shielding, its outer diameter is limited to below 200 mm. Furthermore, the RF input power is restricted such, that any occurring radiation is shielded by the cavity itself. This allows for an RF field on the sample surface of up to about 13 mT.

The first version of RaSTA validated the concept of using the QPR sample geometry in a compact pillbox-like host cavity at 4.8 GHz. Its RF performance was limited by thermal quenches of the host cavity at field levels of about 5 mT, due to the construction using stainless steel flanges with a niobium coating together with copper gaskets. Building on this experience, RaSTA 2.0 was designed to address the limitations of RaSTA 1.0 and to improve the usability.

DESIGN CONSIDERATIONS

A cross section of RaSTA 2.0 is shown in Fig. 1. In terms of the mechanical construction, the design of RaSTA 2.0 was revised in three major aspects:

Improved Cooling of RF Surfaces for a Higher RF Field Limit

The host cavity now uses a bulk copper substrate with reduced thickness, which enhances the thermal conductivity and improves cooling of the RF surfaces. As before, the cavity is demountable to allow the inside to be coated. The sealing concept has been redesigned so that the RF contact between the two cavity parts is ensured with segmented indium wires. At LHe bath temperatures below 3.4 K this results in a fully superconducting Nb/Cu cavity. As before, the high-quality Nb coating is produced at the University of Siegen using HiPIMS with a target thickness of 20 .. 22 µm. The vacuum seal – also to the superfluid LHe bath – is realized with a standard conflat Cu gasket.

Reduced Parasitic Losses and RF Field Asymmetry

Another major aspect of the redesign was the reduction of parasitic losses and RF field asymmetries. These improvements were achieved by introducing dummy RF ports to suppress unwanted dipole components and by implementing

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precise control of the sample mounting height with copper spacers. Ensuring that the sample is mounted within ±100 µm of the optimal position is essential, since the RF field distribution depends sensitively on this parameter.

Redesign of Sample Attachment

The sample is now directly connected to the host cavity without an adapter flange. This lengthens the coaxial line and reduces parasitic RF losses at the bottom end of the coaxial line separating the sample and the host cavity. Without adapter flange, no cleanroom pre-assembly is required which simplifies logistics and reduces the overall turnaround time for experiments. In total, the cold mass of RaSTA has been reduced, which significantly lowers the amount of liquid helium the is required for cooling down the experiment. In a ”standard” vertical test stand this would only affect the cooldown time and the power requirement of the cryo plant. In case of RaSTA, the cryostat is manually filled from mobile Dewar vessels which practically limits the available amount of LHe to few hundred liters.

INDIUM GASKET AND SEALING CONCEPT

In order to quickly test and validate the RF concept of RaSTA, the first version was made from standard vacuum parts that were modified by the in-house workshop at HZB. The host cavity was simply given by a DN 125 CF spacer flange and copper gaskets with reduced inner diameter served as combined vacuum seal and RF joint between the cavity parts. In order to obtain a fully superconducting host cavity, RaSTA 2.0 uses an indium wire gasket instead. The wire is segmented in four pieces with mm-sized gaps in between to evacuate the dead volume up to the conflat gasket that closes the cavity’s vacuum system. This conflat gasket also provides the seal to the superfluid LHe bath.

Simulations show that mm-sized gaps in between the wire segments do not impact the RF current distribution, however mounting precision of this wire gasket is critical for the RF performance of the cavity. For reproducible mounting, a PTFE mold is used that positions the wire on one of the cavity parts. A first test using the copper cavity before niobium coating validated the mounting procedure and showed a homogeneous thickness of the compressed indium wire in the range of 290 to 310 µm. A picture giving the view into the opened copper cavity from above with visible gaskets is shown in Fig. 2.

SAMPLE POSITIONING AND CONTROL OF PARASITIC LOSSES

The calorimetric RF-DC compensation technique used for measuring R_S requires detailed knowledge and control of the RF loss distribution along the entire sample structure. Operation experience with the QPR showed, that even very small fringe fields can cause a significant bias in R_S data [3]. In terms of RaSTA, accurate sample positioning is critical to minimize parasitic losses. CST simulations show that fringe fields can induce unwanted losses in the coaxial line along the sample sidewalls and at the bottom of the sample. To reduce these effects, all surfaces that are exposed to RF fields are niobium-coated, eliminating normal conducting resistive losses at these locations. Special case has to be taken that the sample height after mounting is within ±100 µm of the nomical value (see Fig. 3). This is achieved with a set of copper spacers that can be placed between the sample and the cavity during mounting. Spacers are available with different heights in steps of 100 µm. A laser scanner will be used for contactless height monitoring of all samples before mounting into the cavity.

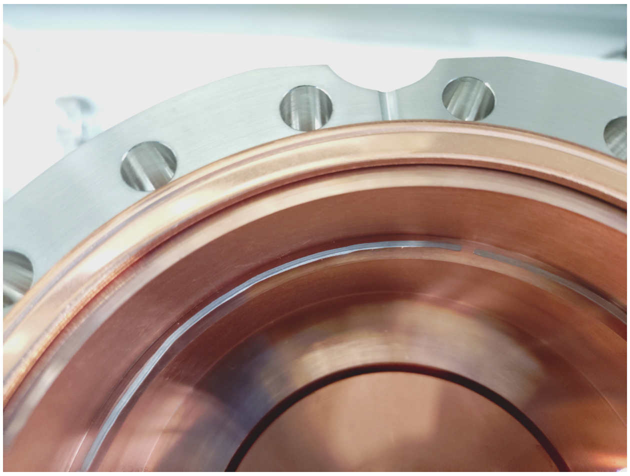

Figure 2: View into the opened copper cavity from above. CF gasket, two indium wire segments and a copper dummy sample are (partly) visible.

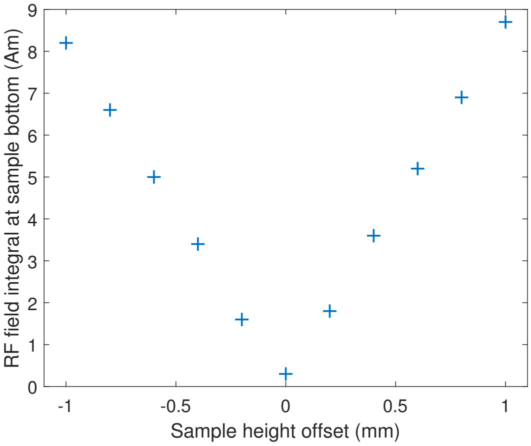

Figure 3: Simulation of the integrated RF field at the bottom of the sample structure as a function of sample height.

FIRST COMMISSIONING RESULTS

After manufacture and before applying the niobium coating, the copper cavity was assembled and tested. A tactile coordinate measuring machine (CMM) was used to check the dimensions of the cavity, sample, and spacers. Special focus was put on the reproducibility of the sample height adjustment by using different spacers and even stacking multiple spacers. This method could be verified, vector network analyzer (VNA) measurements of the TM_{020} mode frequency as a function of sample height are shown in Fig. 4. A constant shift of −5.6 MHz as compared to the design simulations was observed across the measurements. The change of resonant frequency with varying height agrees very well with the expectaton from simulation. By using this commissioning result as a calibration point, VNA measurements can later be used for sample height monitoring. Note, that the frequency vs. height data shows a distinct local maximum at about 100 µm sample offset. Due to this non-monotonic dependence, continuous VNA monitoring during the assembly process is necessary, a single measurement in the final mounting position is not sufficient.

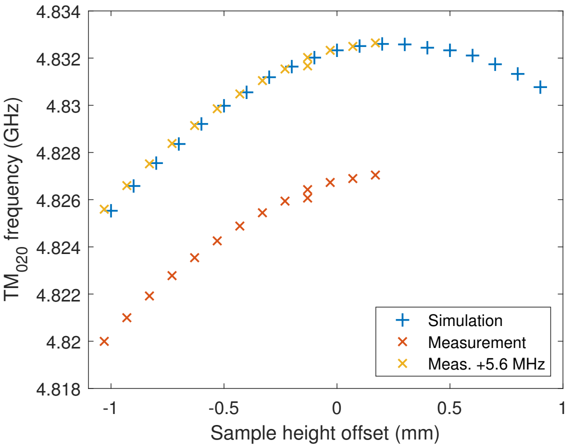

Figure 4: TM_{020} resonant frequency as a function of sample height. First commissioning results of the copper cavity before Nb coating show a systematic shift of -5.6 MHz as compared to CST simulations but very similar dependence on the sample height. Note the non-monotonic behavior (global maximum) when exceeding the nominal mounting position by more than 0.2 mm.

SUMMARY AND OUTLOOK

RaSTA 2.0 is a new sample test cavity complementary to the QPR activities at HZB. It addresses the limitations of version 1.0 such as the thermal RF field limit and parasitic losses. The new cavity design provides higher thermal stability due to the bulk copper cavity body, while the separated sealing concept ensures reliable vacuum performance and a superconducting RF contact. The introduction of copper spacers for height control together with systematic CMM and VNA studies reduces the risk of parasitic losses and improves the measurement accuracy. Simplified assembly procedures and reduced liquid helium requirements make the apparatus more suitable for small laboratory environments without large SRF infrastructure.

The next steps include the assembly of the Nb-coated cavity and first R_S measurements with a known reference sample. A systematic study of Q_0 as a function of liquid helium bath temperature will be performed to assess a possible contribution by the cavity's BCS resistance and the influence of the indium gasket.

In the long term, the goal is to redesign the cavity and sample assembly such that it can be operated with one or two cryocoolers. This would eliminate the need for liquid helium entirely and further broaden the applicability of the setup.

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